# Micro-computed tomography evaluation of the preparation of long oval root canals in mandibular molars with the self-adjusting file

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Abstract: INTRODUCTION: The aim of this study was to assess the shaping potential of a novel nickel-titanium instrument, the self-adjusting file (SAF), in long oval root canals in distal roots in mandibular molars. METHODS: Twenty mandibular molars with long oval distal root canals were selected and scanned preoperatively and postoperatively by using micro-computed tomography at an original resolution of 20 m. Canals were shaped with the SAF, three-dimensionally reconstructed, and evaluated for volume, surface area, canal transportation, and prepared surface. Data were statistically contrasted by using paired t tests and regression analysis. RESULTS: Preoperatively, canal volume was 7.73 ± 2.13 mm(3), and canal area was 42.83 ± 8.14 mm(2). Volumes and surface areas increased significantly (P < .001) by 4.84 ± 1.73 mm(3) and 3.34 ± 1.73 mm(2), respectively, and no gross preparation errors were detected. Unprepared canal surface varied between individual canals, and mean unprepared surface was 23.5% ± 8.9%. Prepared areas were significantly larger compared with rotary canal preparation done in a previous study. Canal transportation scores were higher in the coronal root canal third (106 ± 50 m) compared with the apical third (81 ± 49 m). CONCLUSIONS: In vitro, preparation of long oval-shaped root canals in mandibular molars with the SAF was effective and safe. Moreover, shapes generated with the SAF were more complete compared with rotary canal preparation. Copyright © 2011 American Association of Endodontists. Published by Elsevier Inc. All rights reserved.

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**A micro-computed tomography evaluation of the preparation of long oval root canals in mandibular molars with the self-adjusting file (SAF)**

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**Key words:** self-adjusting file, root canal preparation, micro-computed tomography, Nickel-titanium instruments, long oval root canals

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**Abstract**

**Introduction** The aim of this study was to assess the shaping potential of a novel nickel-titanium instrument, the self-adjusting file or SAF, in long oval root canals in distal roots in mandibular molars. **Methods** Twenty mandibular molars with long oval distal root canals were selected and scanned, pre- and postoperatively, using micro-computed tomography at an original resolution of 20 µm. Canals were shaped with the SAF, three-dimensionally reconstructed and evaluated for volume, surface area, canal transportation and prepared surface. Data was statistically contrasted using paired t-tests and regression analysis. **Results** Preoperatively, canal volume was $7.73 \pm 2.13$ $mm^3$ and canal area was $42.83 \pm 8.14$ $mm^2$. Volumes and surface areas increased significantly ($p<0.001$) by $4.84 \pm 1.73$ $mm^3$ and $3.34 \pm 1.73$ $mm^2$; and no gross preparation errors were detected. Unprepared canal surface varied between individual canals and mean unprepared surface was 23.5±8.9%. Prepared areas were significantly larger compared to with rotary canal preparation done in a previous study. Canal transportation scores were higher in the coronal root canal third (106±50 µm) compared to the apical 1/3 (81±49 µm). **Conclusions** *In vitro*, preparation of long oval-shaped root canals in mandibular molars with the SAF was effective and safe. Moreover, shapes generated with the SAF were more complete compared to rotary canal preparation.

## Introduction

One of the major procedural steps in root canal therapy is to thoroughly remove debris, pulp tissue and microorganisms from the root canal system, which can be accomplished by chemo-mechanical preparation (1). To this end, it has been suggested to prepare canals to a homogenous tapered shape with the prepared canal including the preoperative outline (1,2). However, the root canal system is anatomically complex and mechanical instrumentation may result in preparation errors. Moreover, the use of both conventional hand files and current Nickel-titanium (NiTi) rotary instruments does not result in a fully prepared root canal surface (3).

A funnel-shaped canal with a circular base is not the common configuration in root canal anatomy (2). Recently, cross-sectional root canal configurations have been classified as round, oval, long oval, flattened, or irregular (4). Metrically Jou *at al.* (4) defined “oval” as having a maximum diameter of up to 2 times greater than the minimum diameter and “long oval” as having a maximum diameter of 2 to 4 times greater than the minimum diameter.

A high prevalence of oval and long oval root canals even in the apical root canal portion has been reported (5-7). According to Wu *et al.* (5), the prevalence of long oval root canals in the apical third of human teeth is generally about 25%; in some groups of teeth such as mandibular incisors and maxillary second premolars the prevalence is greater than 50% and in distal roots of mandibular molars the prevalence is 25 to 30%. This complex anatomy may be regarded as one of the major challenges in infection control through root canal preparation.

One aim in the preparation of infected root canals is to remove the inner layer of dentin (8,9). This is particularly hard to achieve when preparing long oval root canals. Furthermore, after preparation, uninstrumented recesses may be left in many oval canals, irrespective of the instrumentation technique, thus leaving debris and unprepared root canal surfaces behind (8,10-14).

All the mentioned studies were done *in vitro*, using extracted teeth that had been sectioned prior to root canal preparation. Then, root cross-sections were assessed before and after preparation, thus representing two-dimensional analyses. In contrast, the technique of micro-computed tomography (MCT) allows a complete description of three-dimensional effects that root canal preparation exerts on root canal anatomy without altering the root during the experiments (3).

This research tool allows calculation of the root canal area that is not mechanically prepared and remains as a so-called untreated surface (15).

Recently, a new instrument type, the self-adjusting file or SAF (ReDent Nova, Ra'anana, Israel), was introduced (16); due to its construction out of a NiTi meshwork, this instrument is believed to expand into long oval root canals and therefore promote a canal preparation that circumferentially removes a layer of dentin in oval as well as round canals (17).

In fact, a recent MCT-based study indicated a superior potential to prepare long oval mesio-buccal canals in maxillary molars with the SAF compared to rotary instrumentation techniques (18), as measured by lesser amounts of untreated canal surface. This measure may be conceived as a three-dimensional indicator for the completeness of a root canal shape, depending on instrument and canal type (19). Preparations of mandibular molar canals with the SAF have not been assessed; therefore, the aim of the current study was to evaluate the prepared surface areas of long oval shaped root canals in mandibular molars with this instrument.

## Materials and Methods

### *Selection of teeth*

From teeth that had been extracted for reasons unrelated to the current study, 20 human mandibular molars were collected and stored in 0.1% thymol solution at 4°C until further use. Teeth initially scanned at an isotropic resolution of 80 µm in a desktop MCT unit (µCT 40, Scanco Medical, Brüttisellen, Switzerland) using previously established methods (15,19). All slices were checked carefully with the distal root tip serving as reference point to count back the slices until the exact slice 6 mm coronal the apex was found. The minimum diameter of the root canal was measured mesio-distally and the maximum diameter was measured bucco-lingually.

Only teeth with a ratio of the maximum to the minimum diameter of more than 2 were selected for further investigation. The mean diameter ratio (maximum divided by minimum cross-sectional distance) in the selected sample was 3.8. Subsequently teeth were mounted on SEM stubs, accessed using high-speed diamond burs and patency of the coronal canal confirmed. Pre-enlargement restricted to the coronal canal third was accomplished with Gates Glidden burs (Dentsply Maillefer, Ballaigues, Switzerland). Subsequently canal lengths and apical patency were determined with size #10 K-files (Dentsply Maillefer) and radiographs; working lengths were set 1 mm shorter than the radiographic apex. A glide path was confirmed at least to a size #20 K-file.

*Root canal instrumentation with the SAF*

The SAF was operated using a trans-line (in-and-out) vibrating handpiece (GENTLEpower, KaVo, Bieberach a. d. Riß, Germany) combined with a RDT3 head (ReDent-Nova) (16) at a frequency of 83.3Hz and an amplitude of 0.4 mm. This movement combined with intimate contact along the entire circumference and length of the canal and the slightly rough surface of the file removes a layer of dentin with a filing motion. The hollow design allows for continuous irrigation throughout the procedure. A special irrigation device (VATEA, ReDent-Nova) was connected to the irrigation hub on the file and provided flow of the irrigant (3% NaOCl) at a flow rate of 5 mL/min.

An SAF 1.5 mm was inserted into each distal canal while vibrating and delicately advanced apically with an intermittent in-and-out hand movement of about 5 mm amplitude, until it reached the pre-determined working length. Each SAF was operated for 4 minutes per canal with continuous irrigation (16); preparations were done by a general practitioner, who had been specifically trained with the SAF instrument. The clinician had also prepared canals with the SAF in maxillary incisors and molars in earlier studies (20).

The clinician was not allowed to see the virtual models of reconstructed teeth before preparing the root canals and during the course of the treatment. This was done so as to avoid bias by an attempt to manually direct the preparation instrument into any potentially un-instrumented area.

*Evaluation*

Virtual root canal models were reconstructed based on MCT scans and superimposed with a precision of better than 1 voxel. Precise repositioning of pre- and various post-preparation images was ensured by a combination of a custom-made mounting device and a software-controlled iterative superimposition algorithm (19,21,22); the resulting color-coded root canal models (green indicates preoperative, red postoperative canal surfaces) enabled quantitative comparison of the matched root canals before and after shaping. From individual canal models, canal volumes up to the level of the cemento-enamel junction (CEJ) as well as in the apical 4 mm were determined using custom-made software (IPL, Scanco Medical) as described previously (19).

Increases in volume and surface area were calculated by subtracting the scores for the treated canals from those recorded for the untreated counterparts. Matched images of the surface areas of the canals, before and after preparation, were examined to evaluate the amount of uninstrumented area. This parameter was expressed as a percentage of the number of static voxel surface to the total number of surface voxels. The cross-sectional appearance, round or more ribbon-shaped was expressed as the structure model index (SMI). This stereological index varies from 1 (parallel plates) to 4 (perfect ball) and was described earlier in more detail (21). Canal transportation was assessed from "centers of gravity" that were calculated for each slice and connected along the z-axis with a fitted line. Mean transportation scores were then calculated by comparing the centers of gravity before and after treatment for the apical, middle and coronal thirds of the canals.

*Comparison data and statistical analysis*

A data set from a previously published study (23) done with the same experimental design was selected to compare the present results. Specifically, the data used refers to group PT/2, in which shaping with ProTaper (Dentsply Tulsa Dental, Tulsa, OK) was done considering buccal and oral aspects each as two individual canals. Normality assumptions in both data sets were verified and therefore data is reported as means±S.D. Original voxel volume in this data set was $8x10^{-6}$ $mm^3$; volume data was rounded to the nearest 1/100 $mm^3$, area data is reported to the nearest 1/100 $mm^2$.

Data for prepared canal surface area is presented as percentages relative to preoperative canal surface areas and canal transportation was rounded to the nearest 1/100 mm distance. For comparison, untreated canal surface scores in the present study were recalculated for 34 µm resolution, since this resolution had been used in a previous study (23).

Regression analysis was used to correlate canal dimension with the amount of untreated surface and preoperative SMI, respectively. Since normality assumptions were verified, means were compared using one-way, as well as repeated measures, ANOVAs followed by Bonferroni/Dunn's tests for post-hoc comparisons or paired t-tests; the level of statistical significance was set at $\alpha$=0.05.

## Results

*SAF preparation*

Distal canals included in the present study had long oval cross-sections, as indicated by a structure model index or SMI, a three-dimensional measure for cross-sectional “flatness”, ranging from 1.3 to 2.6. Volumes and areas ranged from 5 to 13.5 $mm^3$ and from 33.5 to 60.3 $mm^2$, respectively (Tab. 1). Canal preparation with the SAF let to enlarged canal shapes with no evidence of preparation errors (Fig. 1). No SAF instrument fractured during the course of this study; based on red-green color-coded superimposed imaged, shapes were judged satisfactory with evidence of circular dentin removal in most cross-sections (Fig. 1).

Shaping with an SAF for 4 minutes resulted in significantly increased volumes and surface areas ($p<0.001$); dentin removal in individual canals varied between 2.7 and 9.6 $mm^3$ with a mean of $4.84 \pm 1.73$ $mm^3$ (Tab. 2). Canal surface areas increased by $3.34\pm1.73$ $mm^2$.

The SMI showed a small but significant increase to $2.71\pm0.30$ ($p<0.05$). There was no significant correlation between SMI scores and amounts of untreated canal surface ($r^2=0.001$).

Mechanically untreated canal areas overall ranged from 6.7 to 44%. Mean untreated canal surface was 23.4±8.9% for the whole canal length, for the apical; correspondingly in the apical 4 mm, 40.1±13.4% canal surface was counted as untreated.

Mean canal transportations in coronal, middle and apical canal thirds, respectively, were 106±50, 64±36 and 81±49 µm. Canal transportation of 150 µm or more was noted in 8/60 root sections assessed, the majority of which was found in the coronal root canal third. Furthermore, mean canal transportation was larger in the coronal third compared to the middle third ($p<0.01$).

*Comparison to NiTi rotary preparation*

To facilitate direct comparisons, all data was recalculated with 34 µm resolution. This resulted in slight changes in canal volume, area and SMI (~0.5-2%) but in larger amounts of un-treated surface when 34 µm resolution was chosen (Tab. 2). Mean scores describing preoperative canal morphology for specimens included in the present experiment were statistically similar to those in an earlier study (23) on rotary preparation of long oval root canals in mandibular molars (Tab. 1).

Comparing the two shaping techniques, canal enlargement was significantly more pronounced with the SAF ($p<0.002$) and changes in SMI were similar ($p=0.176$). However, SAF preparation resulted in significantly less untreated surface both for the full canal length ($p<0.001$) as well as the apical 4 mm ($p<0.05$) (Tab. 2).

**Discussion**

The main aim of this third study in a series was to assess, using the novel self-adjusting file or SAF, the preparation of root canals with long oval cross-section, based on MCT reconstructions. Distal root canals in mandibular molars represented an adequate model for this experiment and the presented data suggests that preparation of non-round canals with the SAF can be done safely and effective.

This study can be directly compared with earlier material using the same experimental set-up and rotary NiTi instruments. The MCT methodology has been used earlier in studies detailing preparation outcomes with various rotary instruments in maxillary molars. In that tooth group, shaping outcomes appeared to be correlated with preoperative anatomy determined by canal volume (15,19). However, long oval cross-sections constitute a different challenge in mandibular molars.

The number of canals included in the present study (n=20) is higher than in the earlier material (n=10 and 12 per group, respectively) (15,23) and very stringent inclusion criteria were applied in selecting long oval canals; therefore the demonstrated effect of canal preparation strategy on shaping outcomes appears to be robust.Earlier studies (8,13,24) used destructive two-dimensional methods to determine the amount of prepared surface. Using that technique Weiger *et al.* (13) showed that when any amount of preparation was included, between 44 and 68% of the canal surface was unprepared in long oval canals. Similarly, Taha et al. (25) when preparing to an apical size #40 with Hedström files, EndoWave (Morita, Osaka, Japan) or AET (Ultradent, South Jordan, UT), found between 0 and 79% untreated canal wall in oval canals.

The MCT methodology utilized in the present study describes the three-dimensional removal of canal wall dentin by the change in surface voxels, requiring on average the preparation of 20 and 34 µm, respectively, dentin to register as “prepared surface”. A major question addressed with MCT studies is the amount of unprepared surface. The software used in the present study, described in more detail earlier (21, 22), counts a surface voxel as belonging to any given structure when the full voxel belongs to it. Therefore, to be counted as ‘‘treated,’’ at least one full voxel has to be registered as removed from the preoperative canal model after superimposition. In other words, it might very well be the case that a sub-voxel amount of dentin is being shaved off canal wall (the walls were ‘‘touched’’), and no canal wall preparation is registered.

The finer resolution originally employed resulted in higher amounts of prepared surface (~14%) before a recalculation to 34 µm resolution was performed to facilitate direct comparison to rotary instrumentation. The amount of untreated canal surface after SAF preparation was still significantly lower than after rotary instrumentation. Moreover, compared to other studies done with rotaries on rounder maxillary molar canals (15,19), unprepared areas in mandibular molars in the present study were similar when the SAF was used, indicating a particular advantage of this instrument in shaping long-oval canals.

Root canal disinfection appears to be critical for endodontic outcomes (26); eradication of microorganisms occurs as a combination of mechanical preparation (27) and irrigation (28). Irrigation alone is not always effective (29) and mechanical disinfection, related to removal of a layer of infected dentin, is required (30). Continuous irrigation and a homogenous cutting action of the SAF has been shown to lead to smear-layer free and clean canal surfaces (31). Moreover, a recent study demonstrated a significantly more effective disinfection of oval canals *in vitro* with the SAF compared to rotary preparation to a size #40 .04 (32). However, it has not yet been demonstrated that apical irrigant flow and mechanical action of the SAF against canal will predictably remove biofilm in the apical root canal third.

Preparation safety was another factor assessed in the current study. Canal transportation typically was below 100 µm on average and was in the same range than that seen for rotary instrumentation in maxillary molars (15) and distal canals in mandibular molars (data not shown). Moreover, no instrument fractures were noted in the present study and there were little changes to the overall canal shape, suggested by comparatively small increases of the respective structure model index. Taken together with the lack of correlation between treated surface and canal shape indicators suggest that the SAF respects the initial canal anatomy and creates adequate preparations largely independent of preoperative canal anatomy.

Future studies should address clinical outcomes cases following SAF preparation. Such clinical studies will require postoperative observation times of one year and longer but it is anticipated that long oval root canals in particular will be advantageously prepared with the SAF. Another important clinical question is how best to obturate canals prepared with the self-adjusting file; initial data (33) suggest that lateral compaction resulted in a better obturation quality following SAF preparation compared to rotary instrumentation.

In conclusion, preparation of long oval shaped root canals in mandibular molars *in vitro* with the SAF was effective and safe. Moreover, shapes generated with the SAF were more complete compared to rotary canal preparation.

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**Figures and Tables**

FIG. 1: Representative example of micro-computed tomography data of distal canals in mandibular molars, initially (left column) and prepared with the SAF (two middle columns. Preparation time was 4 minutes; length bars 1 mm.

A Three-dimensional views from the buccal, distal and mesial in the top, middle and bottom row, respectively. Green area is unprepared, red area is prepared.

B cross-sections at the levels indicated in part A. Note that unprepared canal is completely enclosed by prepared shape and that Gates Glidden use led to a rounded shape in the coronal section.

TAB. 1: Morphometric data (means ± S.D., n=20) for distal root canals in mandibular molars before preparation with the SAF and NiTi rotaries*.

| | **SAF (20 µm)** | **SAF (34 µm)** | **PT/2*** |
|---|---|---|---|
| Volume [$mm^3$] | 7.73±2.13 | 7.69±2.14 | 7.23±3.23 |
| Area [$mm^2$] | 42.83±8.14 | 41.82±7.9 | 37.52±8.32 |
| SMI [units] | 1.98±0.35 | 2.03±0.30 | 1.98±0.42 |
| Diameter ratio | 3.80±1.24 | 3.80±1.24 | 3.90±1.54 |

SMI: structure model index

*ProTaper group PT/2, data from (23)

TAB. 2: Quantitative assessment of preparation effects (means ± S.D.) for distal canals in mandibular molars prepared with the SAF (n=20) or with NiTi rotaries (n=12). Data for SAF preparation is presented for the original resolution and recalculated.

| | **SAF (20 µm)** | **SAF (34 µm)** | **PT/2*** |
|---|---|---|---|
| Δ Volume [$mm^3$] | 4.84±1.73 | 4.90 ± 1.77 | 2.43 ± 1.13 |
| Δ Area [$mm^2$] | 3.34±1.73 | 3.99±1.75 | n.d. |
| Δ SMI [units] | 0.74±0.17 | 0.66±0.12 | 0.57±0.26 |
| Untreated surface [%] | 23.5±8.9 | 37.4±11.9 | 66.1±15.3 |

SMI: structure model index

n.d.: not determined

*ProTaper group PT/2, data from (23)

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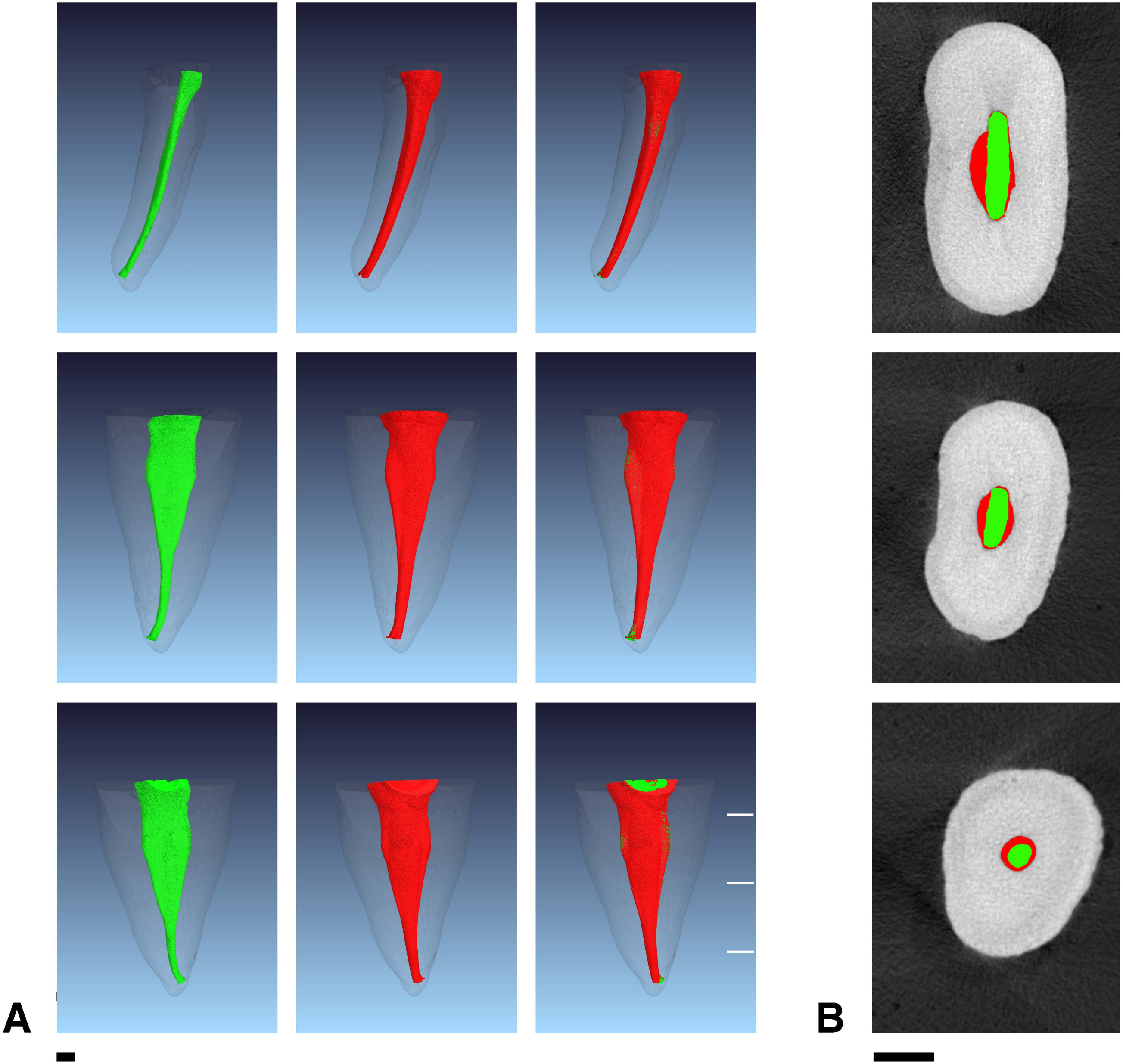
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